# CHAPTER 3. ENGINEERING ANALYSIS

## 3.1 INTRODUCTION

A fluorescent lamp ballast is an electrical device required for starting and operating a fluorescent lamp. The ballast provides the high voltage needed to start the lamps by initiating its discharge and then limits the current to a safe value when the discharge is established.

The starting and operating conditions for each type of fluorescent lamp are specified by lamp manufacturers through the American National Standards Institute (ANSI), Electric Lamp Committee, ANSI C78. The important specifications for lamp life are lamp current, maximum starting voltage, filament voltage, and the lamp current crest factor.[a]

The term *efficacy* is used instead of efficiency when the input and output have different units. The characteristics of fluorescent lamp ballasts are defined by ANSI Specifications C.82.1-1985 and C82.11-1993. They include operating voltage, ballast factor,[b] and power factor.[c] Other standards groups have addressed electromagnetic interference (EMI) and harmonic content for specific applications or environments. Ballasts are now available with total harmonic distortion (THD) less than 10%. Two characteristics not specified by ANSI are ballast efficiency and system (lamp-ballast) efficacy. The ANSI standard for electronic high-frequency ballasts limits harmonics.

This analysis considers three types of fluorescent lamp ballasts: magnetic, cathode cutout, and electronic. There are three methods of starting lamps: pre-heat, rapid-start, and instant-start. Ballasts may also be referred to by the startup method for the lamp with which they are installed (e.g., rapid-start ballast). Pre-heat ballasts are not used in four- or eight-foot commercial and industrial applications in the U.S. and thus are not considered in our analysis. Instant-start ballasts rely upon a higher voltage to initiate the discharge rather than applying a steady filament voltage. Rapid-start ballasts have extra windings to supply a steady filament voltage.

Magnetic ballasts are constructed of discrete components. The main components are a magnetic choke to limit the current, a step-up transformer to obtain a high starting voltage, and a capacitor that corrects for the ballast's low power factor. Multi-lamp magnetic ballasts also have one or more additional capacitors to sequence the starting of the lamps. Magnetic ballasts operate at an input frequency of 60 Hz and operate the lamp(s) at the same frequency.

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[a]The lamp current crest factor is defined as the peak current divided by the root mean square current.

[b]Ballast factor is defined as the ratio of the light output of a lamp tested on a subject ballast divided by the light output of the same lamp tested on a reference ballast under specified environmental conditions.

[c]Power factor is defined as the true power divided by the product of the true rms (root mean squared) value of the voltage across an electrical circuit or device and the true rms current through the circuit or device.

Cathode cutout (CC) ballasts use components similar to those in magnetic rapid-start ballasts but have an electronic switch that disconnects the ballast's lamp electrode heater after the lamp starts. These ballasts use less energy than energy-efficient magnetic ballasts.

Electronic ballasts perform the same function as magnetic ballasts. Electronic fluorescent lamp ballasts are constructed from discrete and integrated components with circuit boards to connect the components. The manufacturing procedures for electronic ballasts are the same as those employed for other electronic devices. Ferrite cores are used for high-frequency output circuits. Electronic ballasts operate at an input frequency of 60 Hz and operate lamp(s) at high frequency, above 20,000 Hz. Electronic ballasts are more efficient than energy-efficient magnetic ballasts in transforming input power to lamp requirements. More significantly, fluorescent lamps are more efficacious when operated at high frequencies (20,000 Hz or above). These two advantages of electronic ballasts may result in a 10 to 30% increase in efficacy for the lamp-ballast system relative to lamps using energy-efficient magnetic ballasts. Because electronic ballasts are packaged in the same size "cans" as magnetic core-coil ballasts, they can be installed in fixtures designed to use core-coil ballasts. Electronic ballasts are easier to install because of their lighter weight.

ANSI C.82.2-1984[1] describes test procedures for evaluating ballast performance by measuring filament voltage, lamp current crest factor, power factor, lamp current, ballast factor, and starting voltage. The measurements are made in a draft-free thermal environment at 25EC.

The ballast efficacy factor (BEF) is a measure of ballast system performance or efficacy. This factor, not explicitly mentioned in the National Appliance Energy Conservation Act (NAECA), is defined as:

$$\text{BEF} = \text{Percent Ballast Factor/Input Power}$$

The BEF is defined as the ballast factor in percent divided by the ballast input power in Watts. The ballast factor (BF) for a subject ballast is the ratio of the light output of a lamp tested on a subject ballast to the light output of the same lamp tested on a "reference" ballast under identical environmental conditions. Reference ballasts for each lamp type are discussed in detail in the relevant ANSI lamp standards.

Lamp types are designated by a series of letters and numbers. The letter "F" is used to designate a fluorescent lamp. It is followed by a two-digit number that identifies either the nominal lamp wattage for rapid-start lamps or the lamp length for instant-start and high-output lamps. These digits are followed by the letter "T," for tubular, which is followed by the lamp diameter in eighths of an inch. Additional designations are sometimes used: for example, "HO" if the lamp is high output, "/ES" if the lamp is an "energy saver" or reduced-wattage lamp, "RE" (if rare earth phosphors have been used), plus a number which represents the color rendering index range. An energy-saver lamp is a reduced wattage, krypton-filled lamp.

The F40T12 and the F96T12 fluorescent lamp ballasts are the only ballasts currently regulated. The minimum BEFs for the existing NAECA standards are listed in Table 3.1. These efficacy factors apply to all ballasts manufactured after January 1, 1990 and sold by manufacturers after April 1, 1991. The standards apply to ballasts operating at input voltages of both 120 and 277 with an input current frequency of 60 Hz. Although the regulated ballasts can operate reduced wattage or energy-saver lamps, all BEF tests are made with 40W F40T12, 75W F96T12, or 110W F96T12HO lamps. The standards do not apply to ballasts that permit dimming, ballasts designed for use in ambient temperatures of 0E F or less, or ballasts that have a power factor less than 0.90 and are designed for use in residential applications.

**Table 3.1 Minimum Allowable Ballast Efficacy Factors**

| Lamp (s) | Voltage | Nominal Lamp Watts | Ballast Efficacy Factor |
|---|---|---|---|
| 1 F40T12 | 120/277 | 40 | 1.805 |
| 2 F40T12 | 120 | 80 | 1.060 |
| 2 F40T12 | 277 | 80 | 1.050 |
| 2 F96T12 | 120/277 | 150 | 0.570 |
| 2 F96T12HO | 120/277 | 220 | 0.390 |

The efficacy of a ballast is defined in terms of lamp lumens per Watt input (lm/W). "Initial" lamp lumens used in calculating efficacy are measured after a lamp has been operated for 100 hours. Light output at 40% of a lamp's lifetime may also be reported in published lamp data.

## 3.2 LAMP/BALLAST COMBINATIONS

Table 3.2 shows the lamp/ballast combinations considered in this analysis. In addition to single ballasts operating one or more lamps, we also consider combinations of ballasts operating three or four lamps. Because the full-wattage halophosphor T12 lamps were rendered obsolete under the Energy Policy Act[d], these lamps are not used in our analysis. All lamps used are "ES" halophosphor lamps because they have replaced full wattage halophosphor F40T12 lamps in the marketplace.

There are very few three- and four- lamp magnetic and cathode cutout ballast models manufactured. Three-lamp fixtures with magnetic or cathode cutout ballasts generally use a two-lamp and a one-lamp ballast, or the lamps may be tandem-wired so that two-lamp ballasts can be employed throughout the lighting layout. Four-lamp fixtures use two two-lamp magnetic, cathode cutout, and electronic T12 ballasts . Compact fluorescent ballasts are not included in this analysis.

[d]For four-foot lamps, the standards took effect in November 1995, and for 8-foot and 8-foot HO lamps in May 1994.

**Table 3.2 Lamp/Ballast Combinations**

| |
|---|
| 1. One-lamp ballast (120, 277V), to operate one 34W F40T12/ES fluorescent lamp |
| 2. Two-lamp ballast (120, 277V), to operate two 34W F40T12/ES fluorescent lamps |
| 3. Two-lamp ballast (120, 277V), to operate two 60W F96T12/ES fluorescent lamps |
| 4. Two-lamp ballast (120, 277V), to operate two 95W F96T12HO/ES fluorescent lamps |
| 5. One, or more ballasts (120, 277V), to operate three 34W F40T12/ES fluorescent lamps |
| 6. One, or more ballasts (120, 277V), to operate four 34W F40T12/ES fluorescent lamps |
| 7. One-lamp ballast (120, 277V), to operate one 32W F32T8 fluorescent lamp |
| 8. Two-lamp ballast (120, 277V), to operate two 32W F32T8 fluorescent lamps; |
| 9. Three-lamp ballast (120, 277V), to operate three 32W F32T8 fluorescent lamps; and |
| 10. Four-lamp ballast (120, 277V), to operate four 32W F32T8 fluorescent lamps. |

## 3.3 TECHNOLOGY OPTIONS

Table 3.3 lists possible technology options that are more efficacious than the baseline energy-efficient magnetic ballast.

**Table 3.3 Technology Options for Fluorescent Lamp Ballasts**

| |
|---|
| 1. Cathode Cutout |
| 2. Electronic High-Frequency Rapid Start |
| 3. Electronic High-Frequency Instant Start |

***Energy-Efficient Magnetic Ballast (Baseline).*** The energy-efficient magnetic (EEM) ballast just meets the minimum NAECA BEFs found in Table 3.1. The EEM ballast employs copper wire and high-grade magnetic materials for its choke and transformer. The EEM ballast could be made even more efficient, but this would increase its size and weight.

***Cathode Cutout Ballast.*** The cathode cutout or hybrid ballast is a modification of the EEM ballast. It uses an electronic circuit to remove filament power after the discharge has been initiated for rapid-start lamps. Cathode cutout ballasts start lamps in the same way that magnetic rapid start ballasts do. Operating lamps without filament power maintains the light output while reducing power by about two Watts per lamp. This approach is effective for dedicated lighting systems where the lamps are operated at full light output. There is a significant loss in lamp life if filament power removal is used with fluorescent dimming systems. The cathode cutout technique is generally used with magnetic ballasts. Some electronic ballast technologies reduce the cathode voltage during operation, but not to zero.

Some data suggest that lamp life is reduced when cathode cutout ballasts are used.[2] For the life-cycle cost analyses in Chapter 4, a 15% reduction in lamp life relative to EEM ballasts is used for both T8 and T12 lamps operated with cathode cutout ballasts.

***Electronic High-Frequency Ballasts***. For equivalent light output, electronic ballasts consume about 10 to 30% less energy than magnetic ballasts. The front end of the electronic ballast converts 60-Hz AC power into DC power. This DC voltage is the input to an oscillating circuit that converts the DC power to a frequency of 20 kHz or higher. The anode fall of the lamp is decreased by about 10 volts at high frequency, resulting in a 10 to 15% increase in the lamp's efficacy. The ballasting action (current-limiting) at high frequency requires smaller components, reducing ballast losses and making the ballast more efficient. Substituting integrated circuits for discrete components saves an additional 1.5 to 2.0 W. High-frequency operation reduces the 60-cycle flicker associated with fluorescent lamps operated with magnetic ballasts. Reducing flicker has been shown to help prevent the headaches and eyestrain sometimes associated with fluorescent lighting.

Electronic ballasts produce high-frequency electromagnetic radiation and carrier line harmonics that are known to interfere with the operation of certain electrical devices such as library proximity sensors, infrared remote controls, powerline carrier controls, and infrared datalinks.[3] Equipment manufacturers are aware of this problem; they have solved it for certain specific applications and are continuing to study the problem as needed.[4]

A rapid-start electronic ballast (ERS) provides a filament voltage to the rapid-start lamp that heats the electrode and allows the lamp to start at a low voltage. The instant-start (EIS) ballast does not provide a filament voltage but must provide a higher starting voltage (than is required for the rapid start lamp) to the instant-start lamp to initiate discharge. This higher starting voltage degrades the coating on the lamp electrodes and reduces lamp life. For the life-cycle cost analyses in Chapter 4, a 25% reduction in lamp life (relative to rapid-start lamps) is used for T8 lamps operated with instant-start ballasts. Eliminating the filament voltage saves about 2 Watts per lamp during operation in instant-start mode. Instant-start operation is not viable for most F40T12 lamps, because their filaments would have to be redesigned.

Electronic ballasts may have difficulties starting 34-Watt F40T12/ES lamps because of the tin oxide conductive coating on the inside of the lamp wall. Lamps without this coating are compatible with electronic ballasts. Such lamps are not currently manufactured; several solutions have been considered by the lamp and ballast industry and rejected as costly and not likely to persist in the market place.

## 3.4 BALLAST WATTAGE DATA

Table 3.4 lists the ANSI Watts, fixture Watts and normalized fixture Watts (for lamp/ballast systems) for several types of magnetic, cathode cutout, and electronic high-frequency ballasts operating F40T12, F96T12, and F32T8 fluorescent lamps. The data sets used to generate Table 3.4 are reproduced in Appendix A and were obtained from the National Electrical Manufacturers Association in all but one case: the one-lamp F40T12/ES cathode cutout ballast. Data came from the New York State Energy Office. The sources[5],[6] used the ANSI procedure C82.2-1984 in developing the data.

The values in the column labeled "ANSI Watts" were obtained from the data set by different approaches depending on whether the ballast was electronic or not, as described below.

For the baseline (EEM) and cathode cutout systems, ANSI Watts were calculated from the formula: ANSI Watts = BF/ BEF, using the average BEF from the data set and the typical BF value of ballasts on the market. Typical EEM ballast BF values are 88% for F40T12/ES, F96T12/ES, and F96T12HO/ES lamps. Average BF values for cathode cutout ballasts are 83% for F40T12/ES lamps and 88% for F96T12HO and F96T12HO/ES lamps. These average BF values are in agreement with published values.[7],[8]

For electronic ballasts, the ballast whose BEF was closest to the 50$^{th}$ percentile level (the next higher level if there was an even number of data points in the data set for that ballast type) was selected from the data set and its measured ANSI Watts and the BF value were used in the tables.

The values in the column labeled "Fixture Watts" were obtained by making corrections to the ANSI Watts. Corrections were applied to ANSI Watts for three- and four-lamp ballast technology options. These corrections account for thermal effects on 1) power input and 2) light output, caused when the lamp/ballast combination is in a fixture and installed in a plenum. Corrections were not made for one- and two-lamp fixtures because thermal effects are thought to be minimal for these configurations. Refer to Appendix A for details on the correction process.

The values in the column labeled "Norm. Fixture Watts" were obtained by applying a correction to all lamp/ballast combinations to normalize light output to the baseline (in addition to the corrections for power input and light output described above). Because all technology options have to be compared to the baseline within a given lamp/ballast combination, each technology option wattage was normalized to the baseline ballast BF. Refer to Appendix A for details on the correction process.

For those cases where an energy-efficient magnetic or cathode cutout ballast does not exist (3- and 4-lamp F40T12/ES ballasts), the normalized fixture wattages in Table 3.4 are for one- and two-lamp/ballast combinations. The normalized fixture watts were obtained by using the normalized fixture watts for one- and two-lamp ballasts in the proper combinations and then applying thermal factor wattage corrections using factors from Table A-1 in the appendix. For the three-lamp tandem-wired system, watts are 1.5 times the two-lamp watts, including electronic systems. In addition, a thermal factor correction was applied. The BF normalization for the EEM and CC systems was performed using a baseline (EEM) BF of 0.88 for ES systems and 0.83 for CC systems.

The values in the column labeled "Fixture Watts" were obtained by making corrections to the ANSI Watts. The correction applied to the ANSI Watts for three- and four-lamp ballast technology options is a thermal correction factor for power input, required when the lamp/ballast combination is in a fixture and installed in a plenum. For the "Norm. Fixture Watts" column, a power correction factor to normalize light output to the baseline is also applied to the lamp/ballast combinations noted in the text , that is, each technology option wattage was normalized to the baseline ballast BF. Refer to Appendix A for details on the correction process. The F32T8 system normalized fixture Watts have been further adjusted for equivalent lamp lumen output , as discussed in the next section.

**Table 3.4 ANSI Watts, Fixture Watts, and Normalized Fixture Watts**

| Ballast | Energy-Efficient Magnetic | | Cathode Cutout | | Rapid-Start Electronic | | | Instant-Start Electronic | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lamp | ANSI Watts | Norm. Fixture Watts* | ANSI Watts | Norm. Fixture Watts* | ANSI Watts | Fixture Watts | Norm. Fixture Watts* | ANSI Watts | Fixture Watts | Norm. Fixture Watts* |
| 1 F40T12/ES | 42.3 | 42.3 | 36.7 | 38.9 | 31.1 | 31.1 | 32.4 | NA | NA | NA |
| 2 F40T12/ES | 72.4 | 72.4 | 62.2 | 65.9 | 65.9 | 65.9 | 62.0 | NA | NA | NA |
| 3 F40T12/ES (tandem-wired) | NA | 104.3 | NA | 94.9 | NA | NA | 91.1 | NA | NA | NA |
| 3 F40T12/ES (not tandem-wired) | NA | 110.1 | NA | 100.6 | NA | NA | 94.3 | NA | NA | NA |
| 4 F40T12/ES | NA | 139.0 | NA | 126.5 | NA | NA | 121.5 | NA | NA | NA |
| 2F96T12/ES | 126.1 | 126.1 | NA | NA | NA | NA | NA | 113.2 | 113.2 | 111.3 |
| 2F96T12HO/ES | 200.0 | 200.0 | 185.3 | 185.3 | 176.3 | 176.3 | 176.5 | NA | NA | NA |
| 1 F32T8 | NU | NU | NA | NA | 29.7 | 29.7 | 27.2 | NU | NU | NU |
| 2 F32T8 | NU | NU | NU | NU | 61.3 | 61.3 | 54.2 | NU | NU | NU |
| 3 F32T8 (tandem) | NU | NU | NU | NU | NA | 87.4 | 77.3 | NU | NU | NU |
| 3 F32T8 | NA | NA | NA | NA | 94.3 | 89.6 | 75.8 | NU | NU | NU |
| 4 F32T8 | NA | NA | NA | NA | 122.8 | 116.7 | 103.2 | NU | NU | NU |

Notes:
NA = not available or applicable.
NU = not used for this analysis..

Note that the normalized fixture Watts are used for the purposes of this analysis to compare baseline and technology options on the basis of equivalent light output. Other types of energy calculations typically done with fixture Watts are representative of actual wattages of ballasts on the market.

## 3.5 EFFICIENCY AND ENERGY USE DATA

### 3.5.1 Data for T12 Lamps

The values of BF, BEF, and normalized fixture Watts that appear in Table 3.5 were derived using the procedures described in section 3.4. Energy use was computed by multiplying the normalized fixture Watts by the annual lighting hours. Table 3.5 shows data for T12 lamps only. We found that each type of ballast (e.g., electronic 2F40T12) exhibited a range of BEFs in the marketplace. The BEFs shown above are the median (50$^{th}$ percentile) efficiencies that were used for energy calculations. For setting standards, DOE would use the 10$^{th}$ percentile BEF.

The annual lighting hours were derived from a large data set of energy audits done throughout the U.S.[9] Annual interior lighting hours were calculated for the industrial sector and for 10 commercial building types: office, retail, grocery, restaurant, lodging, health, assembly, school, college, and warehouse. To derive commercial sector lighting hours, hours for the different building types were weighted using CBECS 1992 national square footage for each building type.[10] Then these hours were adjusted to account for the fact that magnetic ballasts, which are affected by standards, tend to be used for fewer hours than other types of ballasts. In contrast, electronic ballasts tend to have longer hours because users in buildings where the lighting is heavily used tend to switch to efficient ballasts. The weighted averages of the commercial sector annual lighting hours for the different lamp types are: 3,400 hours per year for F40T12 and F32T8; 3,300 hours for F96T12; and 3,700 hours for F96T12HO. The industrial sector annual lighting hours for the applicable lamp types are: 3,700 hours for F96T12 and 4600 hours for F96T12HO. Commercial sector hours are used for the F40T12, F32T8, and F96T12 lamp types; industrial hours are used for the F96T12HO lamp type. Sensitivity runs were also performed using industrial sector hours for F96T12 and commercial sector hours for F96T12HO lamp types, as shown in Chapter 4. Appendix A contains details of the lighting hours calculations.

## Table 3.5 Efficiency and Energy-Use Data for Fluorescent Lamp Ballasts Operating T12 Lamps

| Ballast Type | | Normalized Fixture Watts | Annual Energy Use (kWh/yr) | Ballast Factor | BEF |
|---|---|---|---|---|---|
| **1 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **1F40 T12/ES** | 42.3 | 144 | 0.88 | 2.08 |
| **Cathode Cutout** | **1F40 T12/ES** | 38.9 | 132 | 0.83 | 2.26 |
| **Electronic, Rapid Start** | **1F40 T12/ES** | 32.4 | 110 | 0.85 | 2.72 |
| **2 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **2F40 T12/ES** | 72.4 | 246 | 0.88 | 1.22 |
| **Cathode Cutout** | **2F40 T12/ES** | 65.9 | 224 | 0.83 | 1.34 |
| **Electronic, Rapid Start** | **2F40 T12/ES** | 62.0 | 211 | 0.94 | 1.42 |
| **3 Lamp Fixture - tandem wired (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **(1.5) 2F40 T12/ES** | 104.3 | 355 | 0.88 | NA |
| **Cathode Cutout** | **(1.5) 2F40 T12/ES** | 94.9 | 323 | 0.83 | NA |
| **Electronic, Rapid Start** | **(1.5) 2F40 T12/ES** | 91.1 | 310 | 0.87 | 0.91 |
| **3 Lamp Fixture - not tandem wired (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **1F40 & 2F40 T12/ES** | 110.1 | 374 | 0.88 | NA |
| **Cathode Cutout** | **1F40 & 2F40 T12/ES** | 100.6 | 342 | 0.83 | NA |
| **Electronic, Rapid Start** | **3F40 T12/ES** | 94.3 | 317 | 0.87 | 0.91 |
| **4 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **(2) 2F40 T12/ES** | 139.0 | 473 | 0.88 | NA |
| **Cathode Cutout** | **(2) 2F40 T12/ES** | 126.5 | 430 | 0.83 | NA |
| **Electronic, Rapid Start** | **(2) 2F40 T12/ES** | 121.5 | 413 | 0.94 | NA |
| **2F96 T12/ES (Commercial)** | | | | | |
| ***3,300 annual hours, 15.2-yr life*** | | | | | |
| **Baseline** | | 126.1 | 416 | 0.88 | 0.70 |
| **Electronic, Instant Start** | | 111.3 | 367 | 0.90 | 0.79 |
| **2F96 T12/ES (Industrial)** | | | | | |
| ***3,700 annual hours, 13.5-yr life*** | | | | | |
| **Baseline** | | 126.1 | 467 | 0.88 | 0.70 |
| **Electronic, Instant Start** | | 111.3 | 412 | 0.90 | 0.79 |

**Table 3.5 (continued)**

| Ballast Type | Normalized Fixture Watts | Annual Energy Use (kWh/yr) | Ballast Factor | BEF |
|---|---|---|---|---|
| **2F96 T12HO/ES (Commercial)** | | | | |
| ***3,700 annual hours, 13.5-yr life*** | | | | |
| **Baseline** | 200.0 | 740 | 0.88 | 0.44 |
| **Cathode Cutout** | 185.3 | 686 | 0.88 | 0.48 |
| **Electronic, Rapid Start** | 176.5 | 653 | 0.88 | 0.50 |
| **2F96 T12HO/ES (Industrial)** | | | | |
| ***4,600 annual hours, 10.9-yr life*** | | | | |
| **Baseline** | 200.0 | 920 | 0.88 | 0.44 |
| **Cathode Cutout** | 185.3 | 852 | 0.88 | 0.48 |
| **Electronic, Rapid Start** | 176.5 | 812 | 0.88 | 0.50 |

BEF = BF / ANSI Watts
NA = not applicable (multiple ballast system)

### 3.5.2 Data For T8 Lamps

A separate set of data were collected to compare T8 magnetic lamp/ballast systems to T8 electronic lamp/ballast systems. One and two-lamp ballast combinations were analyzed. Table 3.6 shows the wattage, BF and BEF data for those two combinations. The fixture watts, BEFs and BFs for magnetic, cathode cutout and electronic ballasts are from the July, 1997 report. The normalized fixture watts (shown in Table 3.6) are obtained by adjusting the fixture watts for equal light output using the BFs shown in the same table (Table 3.6).

**Table 3.6 Efficiency and Energy-Use Data for Fluorescent Lamp Ballasts Operating T8 Lamps**

| Ballast Type | | Normalized Fixture Watts | Annual Energy Use (kWh/yr) | Ballast Factor | BEF |
|---|---|---|---|---|---|
| **1 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **1F32 T8/RE70** | 38.8 | 132 | 0.95 | 2.45 |
| **Electronic, Rapid Start** | **1F32 T8/RE70** | 32.8 | 112 | 0.86 | 2.90 |
| **Electronic, Instant Start** | **1F32 T8/RE70** | 32.0 | 109 | 0.91 | 2.97 |
| **2 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **2F32 T8/RE70** | 74.3 | 253 | 0.95 | 1.28 |
| **Cathode Cutout** | **2F32 T8/RE70** | 69.5 | 236 | 0.86 | 1.37 |
| **Electronic, Rapid Start** | **2F32 T8/RE70** | 65.3 | 222 | 0.89 | 1.46 |
| **Electronic, Instant Start** | **2F32 T8/RE70** | 63.0 | 214 | 0.89 | 1.50 |

## 3.6 CONSUMER SUBGROUP ANALYSIS

When end-users replace a T12 EEM ballast with an electronic ballast, some will choose to convert to a T8 lamp system and will utilize a T8ERS or T8EIS ballast. In the current market, about 95% of electronic ballast purchasers are selecting T8 electronic ballasts and only 5% T12 electronic ballasts. In order to calculate national energy savings from some standards scenarios requiring electronic ballasts, the additional analysis shown below was performed so that such conversions would be accounted for.

Table 3.7 shows the F32T8 systems grouped with the baseline (EEM ballast) systems they would replace in the market. Their normalized fixture Watts have been adjusted so that their light output is equivalent to the baseline light output. Two adjustments are made: first there is a BF adjustment and second there is a lumens adjustment. The lumens adjustment is described below. The BF adjustment is similar to that done for T12 lamp/ballasts systems.

**Table 3.7 Efficiency and Energy-Use Data for Fluorescent Lamp Ballasts Operating T12 Lamps and T8 Lamps**

| | Ballast Type | Normalized Fixture Watts | Annual Energy Use (kWh/yr) | Ballast Factor | BEF |
|---|---|---|---|---|---|
| **1 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **1F40 T12/ES** | 42.3 | 144 | 0.88 | 2.08 |
| **Cathode Cutout** | **1F40 T12/ES** | 38.9 | 132 | 0.83 | 2.26 |
| **Electronic, Rapid Start** | **1F40 T12/ES** | 32.4 | 110 | 0.85 | 2.72 |
| **Electronic, Rapid Start** | **1F32 T8/RE70** | 27.2 | 92 | 0.86 | 2.90 |
| **2 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **2F40 T12/ES** | 72.4 | 246 | 0.88 | 1.22 |
| **Cathode Cutout** | **2F40 T12/ES** | 65.9 | 224 | 0.83 | 1.34 |
| **Electronic, Rapid Start** | **2F40 T12/ES** | 62.0 | 211 | 0.94 | 1.42 |
| **Electronic, Rapid Start** | **2F32 T8/RE70** | 54.2 | 171 | 0.89 | 1.46 |
| **3 Lamp Fixture - tandem wired (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **(1.5) 2F40 T12/ES** | 104.3 | 355 | 0.88 | NA |
| **Cathode Cutout** | **(1.5) 2F40 T12/ES** | 94.9 | 323 | 0.83 | NA |
| **Electronic, Rapid Start** | **(1.5) 2F40 T12/ES** | 91.1 | 310 | 0.87 | NA |
| **Electronic, Rapid Start** | **(1.5) 2F32 T8/RE70** | 77.3 | 238 | 0.89 | NA |
| **3 Lamp Fixture - not tandem wired (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **1F40 & 2F40 T12/ES** | 110.1 | 374 | 0.88 | NA |
| **Cathode Cutout** | **1F40 & 2F40 T12/ES** | 100.6 | 342 | 0.83 | NA |
| **Electronic, Rapid Start** | **3F40 T12/ES** | 94.3 | 317 | 0.87 | 0.91 |
| **Electronic, Rapid Start** | **3F32 T8/RE70** | 75.8 | 238 | 0.93 | 0.99 |
| **4 Lamp Fixture (Commercial Sector)** | | | | | |
| ***3,400 annual hours, 14.7-yr life*** | | | | | |
| **Baseline** | **(2) 2F40 T12/ES** | 139.0 | 473 | 0.88 | NA |
| **Cathode Cutout** | **(2) 2F40 T12/ES** | 126.5 | 430 | 0.83 | NA |
| **Electronic, Rapid Start** | **(2) 2F40 T12/ES** | 121.5 | 413 | 0.94 | NA |
| **Electronic, Rapid Start** | **4F32 T8/RE70** | 103.2 | 307 | 0.89 | 0.73 |

**BEF = BF / ANSI Watts**
**NA = not applicable (multiple ballast system)**

All of the BEF data in Tables 3.5, 3.6 and 3.7 have associated uncertainties. There are two sources of uncertainty in BEF values: measurement error and variability in the manufacturing process. A series of eight repeated measurements using the ANSI test method was made by one ballast manufacturer under well-controlled laboratory conditions on the same lamp/ballast combination. The range in BEF calculated from these measurements is 2.969 to 3.014 for a ballast operating one T8 lamp and 1.523 to 1.537 for a ballast operating two T8 lamps. These tests show that an absolute measurement error in the BEF of 0.045 for the one-lamp F32 ballast and 0.014 for the two-lamp F32 ballast may exist. Data from industry on production runs in excess of 1,000 units indicate an average production run variation in BEF of ±2 percent.

The lumen adjustment is described as follows. The Average Maintained Illumination Calculation [The Lumen Method as illustrated on pages 405 of the $8^{th}$ Edition of the Illuminating Engineering Society's Lighting Handbook] is defined as follows:

$$\text{Illuminance} = \frac{\text{(Number of Luminaires)} \times \text{(Lumens per Luminaire)} \times \text{(CU)} \times \text{(Light Loss Factors)}}{\text{Area}}$$

The following is a description of the terms in the formula.

1) **Illuminance**
Illuminance is the density of the luminous flux incident on a surface: It is the quotient of the luminous flux by the area of the surface when the area is uniformly illuminated. Illuminance is measured in footcandles; one footcandle equals one lumen per square foot.

2) **Number of Luminaires**
A luminaire is a complete lighting unit consisting of a lamp or lamps together with the parts designed to position and protect the lamps and connect them to a power supply. A more common term is "fixture." Each luminaire is designed for and has the components for a specific number of lamps.

3) **Lumens per Luminaire**
Lumens per Luminaire is the rated initial lumens, or light output, of the lamp, multiplied by the number of lamps in the fixture.

4) **CU** (Coefficient of Utilization)
The CU is the ratio of the lumens from a fixture calculated as received on the work plane to the total lumens emitted by the fixture's lamps.

5) **Light Loss Factors**
Light loss factors are used to represent reduction in illuminance levels after a given period of time. These factors take into account temperature and voltage variations; dirt accumulation on the walls, fixtures, and lamps; lamp lumen depreciation, etc.

When comparing T8 lamp systems with T12 systems, lumen depreciation is the only relevant light loss factor. It relates specifically to the type of lamp used. All other factors are common to fixtures equipped with T8 lamps and the same fixtures equipped with T12 lamps. The rate of lumen depreciation for an F40T12/ES lamp is higher than that for an F32T8/RE70 lamp. An analysis that includes both lamp options must account for lumen depreciation in its calculations.

For the purposes of this analysis, we have used an illuminance equation that incorporates lamp lumen depreciation with "Lumens per Luminaire " as shown below.

$$\text{Illuminance (at 40\% of lamp's rated life)} = \frac{\text{(\# of Luminaires) x (Mean Lumens per Luminaire) x (Other Light Loss Factors) x (CU)}}{\text{Area}}$$

The value "Mean Lamp Lumens" is used to represent lamp light output after some lamp lumen depreciation has occurred. The actual value used is an average of "Mean Lumen" from the 22nd edition of the *GE Lighting 9200 Lamp Catalog* and *Design Lumen* from June 1997 edition of the *Philips Lamp Specification and Application Guide*. Both catalogs define these values as the approximate lumen output when a lamp has reached 40% of its rated life. As with the standard IES formula, this value is multiplied by the number of lamps in the fixture to get the fixture's total mean lumens. Osram/Sylvania's 1996 Product catalog does not include a reference to each lamp's light lumen output at 40% of rated life. Table 3.8 shows the mean lumens values used for these analyses.

The coefficient of utilization is a function of lamp type, ballast type and room properties. Some of the impact of CU on illuminance is already accounted for by the thermal correction factors described earlier. There may be additional corrections required to normalize light output when T12 systems are compared to T8 systems. At this time, we have not yet completed an analysis to determine what additional correction, if any, is needed. Such a correction (CU ratio), would tend to increase energy savings when converting from a T12 to a T8 system (if equal light output is required).

**Table 3.8 Mean Lumens**

| Level | Description | Lamp Type | Mean Lumens |
|---|---|---|---|
| **4ft 1-LAMP FIXTURE** | | | |
| 0 | EEM | 1F40T12/ES | 2,290 |
| 1 | CC | 1F40T12/ES | 2,290 |
| 2 | ERS T12 | 1F40T12/ES | 2,290 |
| 3 | ERS T8 | 1F32T8/RE70 | 2,560 |
| **4ft 2-LAMP FIXTURE** | | | |
| 0 | EEM | 2F40T12/ES | 4,580 |
| 1 | CC | 2F40T12/ES | 4,580 |
| 2 | ERS T12 | 2F40T12/ES | 4,580 |
| 3 | ERS T8 | 2F32T8/RE70 | 5,120 |
| **4ft 3-LAMP FIXTURE (tandem wired)** | | | |
| 0 | EEM | 1.5X2F40T12/ES | 6,870 |
| 1 | CC | 1.5X2F40T12/ES | 6,870 |
| 2 | ERS T12 | 1.5X2F40T12/ES | 6,870 |
| 3 | ERS T8 | 1.5X2F40T12/ES | 7,680 |
| **4ft 3-LAMP FIXTURE (not tandem wired)** | | | |
| 0 | EEM | 1F40+2F40T12/ES | 6,870 |
| 1 | CC | 1F40+2F40T12/ES | 6,870 |
| 2 | ERS T12 | 3F40T12/ES | 6,870 |
| 3 | ERS T8 | 3F32T8/RE70 | 7,680 |
| **4ft 4-LAMP FIXTURE** | | | |
| 0 | EEM | 2X2F40T12/ES | 9,160 |
| 1 | CC | 2X2F40T12/ES | 9,160 |
| 2 | ERS 12 | 2X2F40T12/ES | 9,160 |
| 3 | ERS T8 | 4F32T8/RE70 | 10,240 |

## 3.7 PRICE - EFFICIENCY

The discussion below describes how we developed ballast prices and incremental ballast prices. Because there are ballasts in the market at all of the efficiency levels considered by DOE, we determined incremental ballast prices for various efficiency levels by collecting information in the marketplace. However, it is difficult to obtain end-user pricing. In most instances, ballasts, either in fixtures or not in fixtures, are purchased by contractors from electrical distributors. The contractor installs the fixtures and/or ballasts in a building and bills the owner for the job. Thus the end-user ballast price is buried within the job invoice. To obtain end-user prices, the 1997 Draft Report used ballasts prices derived from a data collection effort by Gough and Associates (G&A) conducted for LBNL. G&A collected data at points in the distribution chain where ballasts were sold individually and applied markups to estimate end-user prices. These markups, provided by respondents to a G&A survey of ballast and fixture manufacturers, were difficult to obtain and to verify.

We reexamined the methodology used to obtain ballast prices for the 1997 Draft Report. DOE has decided to use a more direct approach, starting with distributor to contractor prices for both ballasts in fixtures and not in fixtures. Thus, only one markup, segments G and H in the NEMA-provided ballast distribution channel chart (see Figure 1 below), was needed to arrive at an end-user price.

As described above, we gathered new ballast price data from distributors of magnetic and electronic ballasts which contains only one markup between the distributor selling price and the end-user price, for which we are using 13 percent. The department has used 13 percent in past analyses, without any comment, and it was also used by NEMA in material sent to DOE in July 1998. We obtained prices for ballasts not in fixtures and for fixtures equipped with ballasts. Ballasts not in fixtures are assumed to represent 37 percent of the market, and ballasts in fixtures are assumed to represent 63 percent of the market. These weights come from NEMA comment # 27, p. 8 where 37 percent is for the "distributor + LMC channel" and 63 percent is for the "OEM channel."

With the goal of gathering ballast price data, LBNL attempted to contact two electrical distributors per state in late 1998 and January 1999. The first 26 distributors were taken from the Yellow Pages for 25 major metropolitan areas around the country. The remaining 74 electrical distributors were selected from the American Wholesalers & Distributers Directory (5th Ed., Holly M. Selden & Jane A. Malonis Editors, 1997 by Gale Research) After an initial phone call, letters of confidentiality and a list of six fluorescent ballasts and six common fixtures were faxed to 60 distributors who agreed to provide pricing information. Each of these distributors received a follow-up call. As of February 4, 1999, pricing data had been received from 27 electrical distributors in 19 different states. However, not all of the distributors provided prices for all six of the ballasts listed or for the six common fixtures equipped with these ballasts.

Each distributor was asked to give a contractor price for each of the ballasts, assuming an order for 100 of any given ballasts, for a "good" client. Lower quantity purchases could result in higher prices and higher quantity purchases could result in lower prices. Table 3.9 below lists the six individual ballasts (not in fixtures) and the average of the prices we received from the distributors plus an assumed 13% contractor markup.

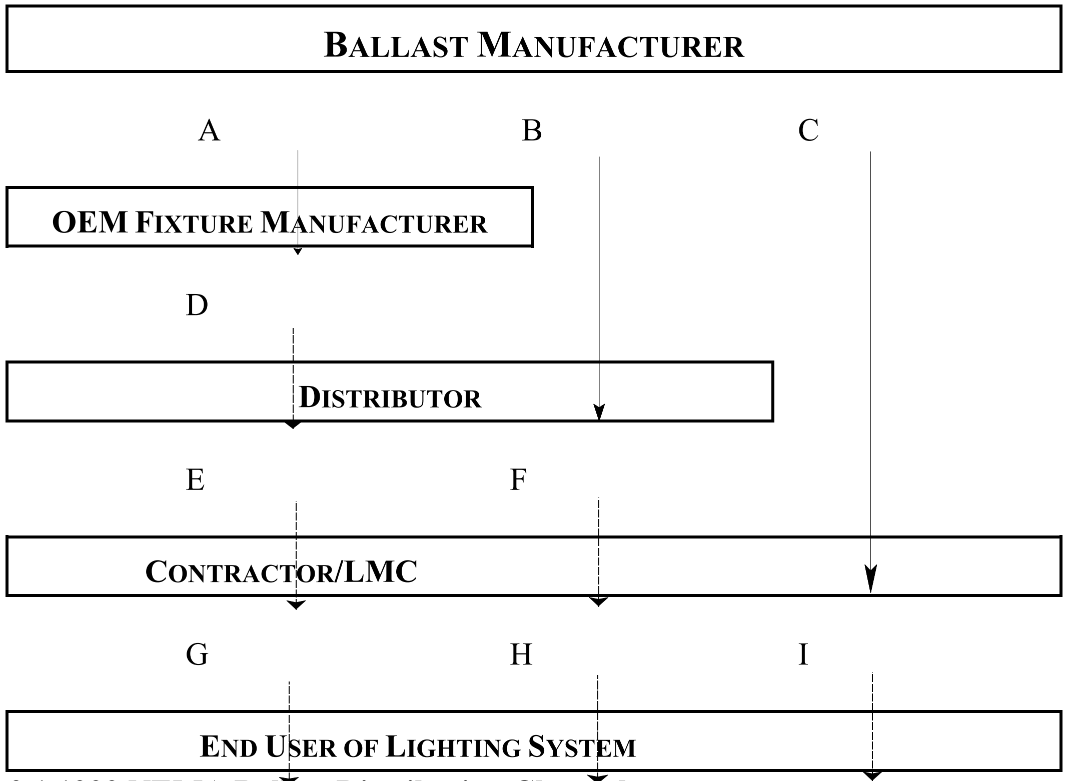


**Figure 3.1 1999 NEMA Ballast Distribution Channels**

**Table 3.9 1999 Ballast (Not in Fixtures) Price Data**

| Ballast | # of Quotes | Average Price + 13% |
|---|---|---|
| Magnetic for 2 F40T12/ES lamps | 17 | $13.16 |
| Electronic for 2 F40T12/ES lamps | 17 | $23.62 |
| Magnetic for 2 F96T12/ES lamps | 11 | $21.63 |
| Electronic for 2 F96T12/ES lamps | 11 | $32.08 |
| Electronic for 2 F32T8 lamps | 21 | $20.10 |
| Electronic for 4 F32T8 lamps | 10 | $22.48 |

We received more quotes than are listed in the table above. For T12 lamps, we only used prices from distributors who provided a price for both magnetic and electronic ballasts. We did this because we wanted the most direct price differences between magnetic and electronic ballasts for T12 systems from the same source. For T8 lamps, the full range of prices received was used to calculate the average.

Each distributor was also asked to give a contractor price for six common fixtures equipped with the six fluorescent ballasts listed above. They were asked to assume that the order would be for 100 of the given fixture, and was for a “good” client. Table 3.10 below lists the common fixtures, each equipped with one or more of the six ballasts and the average of the prices we received from the distributors plus a 13% contractor markup. All of the fixtures for four-foot lamps are contractor-grade recessed troffers with 277-Volt ballasts and standard prismatic lenses. The fixtures for the eight-foot lamps are general-purpose strip fixtures with 277-Volt ballasts.

**Table 3.10 1999 Fluorescent Fixture Price Data**

| Fixture Description | Lamp | # of Ballasts | # of Quotes | Price with Magnetic Ballast + 13% | Price with Electronic Ballast + 13% |
|---|---|---|---|---|---|
| Recessed 2-lamp lensed troffer | 2F40T12/ES | 1 | 11 | $42.58 | $54.55 |
| Recessed 4-lamp lensed troffer | 4F40T12/ES | 2 | 13 | $47.45 | $62.22 |
| General Purpose Strip - 2 lamp | 2F96T12 | 1 | 10 | $32.63 | $54.05 |
| Recessed 2-lamp lensed troffer | 2F32T8 | 1 | 8 | Data not requested | $51.80 |
| Recessed 4-lamp lensed troffer | 4F32T8 | 1 | 9 | Data not requested | $47.43 |

We received more quotes than are listed in the table above. For T12 lamps, we only used prices from distributors who provided a price for both magnetic and electronic ballast. We did this because we wanted the most direct price differences between magnetic and electronic ballasts for T12 systems from the same source. For T8 lamps, the full range of prices received was used to calculate the average.

NEMA also provided DOE with the results of its attempt to obtain prices for ballasts sold in fixtures. NEMA asked fixture manufacturers for an estimate of the industry average differential in selling price from fixture manufacturer to distributors (segment D in Figure 3-1 NEMA’s figure showing different channels from ballast manufacturer to end user) among fixtures that were identical except for their ballasts. From these data, NEMA provided DOE with a ratio of the manufacturer price of a luminaire with electronic ballasts to one with magnetic ballasts. Then, using these data along with certain assumptions about fixture prices and mark-ups, NEMA arrived at end-user prices for ballasts in fixtures. We have decided not to use this approach because the various assumptions are not documented, because fixture manufacturers were not asked to provide their own prices (which they would have known precisely), and because this approach does not provide any information about the range of possible prices. However, we did examine the results of the NEMA approach and found that NEMA’s prices and ratios of fixture prices fall within the ranges of data used in our analysis as discussed below.

***Weighted Average Ballast Prices***. Having an average price for ballasts not in fixtures (Table 3.9), we then determined an average price for ballasts in fixtures from the data in Table 3.10 and weighed them together to obtain an average incremental ballast price for use in our LCC analysis. We calculated the incremental price for an electronic ballast in a fixture by subtracting the price for a fixture equipped with a magnetic ballast from the price of the same fixture when equipped with an electronic ballast. The average of all the incremental prices is assumed to represent the incremental cost of the electronic ballast(s) in the fixture over and above the price of the baseline ballast's average price. We used the T12 magnetic ballast price (not in a fixture) to be the baseline ballast because we cannot directly obtain the ballast portion of a fixture price. We therefore made the assumption that the price of the baseline EEM ballast was the same whether sold by itself or as part of a fixture. This assumption affects the absolute ballast prices but does not affect the incremental price of an electronic ballast relative to a magnetic ballast. Given the above, the price of an electronic ballast is obtained as shown in Table 3.11 by the following:

| | |
|---|---|
| Column 1 | The average price of the magnetic (EEM) baseline ballast(s) not in fixture |
| Column 2 | The average price of the electronic ballast(s) not in fixture |
| Column 3 | The average incremental price for the electronic ballast(s) not in fixture, column 2 minus column 1 |
| Column 4 | The average price of the fixture associated with a magnetic (EEM) ballast |
| Column 5 | The average price of the fixture equipped with an electronic ballast |
| Column 6 | The average incremental price for the fixture with electronic ballast, column 5 minus column 4 |
| Column 7 | Weighted average electronic ballast incremental price: average incremental price of electronic ballast not in fixture, column 3, multiplied by a weight of 0.37 plus average incremental price of electronic ballast not in fixture, column 6, multiplied by a weight of 0.63. |
| Column 8 | Weighted average electronic total price of electronic: weighted average incremental electronic ballast price, column 7, added to the average price of the stand-alone EEM ballast, column 1. |

In the case of 3F40T12 and 3F32T8 tandem-wired electronic ballasts, the weighted price is 1.5 times the price of the corresponding two-lamp electronic ballasts. This reflects the fact that existing wiring configurations will require three 2F40T12 or 2F32T8 electronic ballasts to be tandem-wired between two three-lamp fixtures.

The price for non-tandem wired 3F40T12 electronic ballasts is calculated by the same process as described above. However, in this case, the price of an EEM ballast (column 1) is actually the sum of the price for a 1F40T12 and a 2F40T12 EEM ballast.

## Table 3.11 Weighted Prices for Ballasts

2F40T12 Electronic Ballast Price

| Column 1<br>2F40T12 EMAG (ballast not in fixture) | Column 2<br>2F40T12 EL (ballast not in fixture) | Column 3<br>Incre-mental Price | Column 4<br>2F40T12 EMAG Troffer (ballast + fixture) | Column 5<br>2F40T12 EL Troffer (ballast + fixture) | Column 6<br>Average Incremental Price for Electronic Ballast | Column 7<br>Weighted Electronic Average Incremental Price | Column 8<br>Weighted Electronic Average Total Price |
|---|---|---|---|---|---|---|---|
| $ 13.16 | $ 23.62 | $ 10.46 | $ 42.58 | $ 54.55 | $ 11.97 | $ 11.41 | $ 24.57 |

2F32T8 Electronic Ballast Price

| 2F40T12 EMAG (ballast not in fixture) | 2F32T8 EL (ballast not in fixture) | Incre-mental Price | 2F40T12 EMAG Troffer (ballast + fixture) | 2F32T8 EL Troffer (ballast + fixture) | Incremental Price | Weighted Incremental Price | Weighted Total Price |
|---|---|---|---|---|---|---|---|
| $ 13.16 | $ 20.10 | $ 6.94 | $ 42.58 | $ 51.80 | $ 9.22 | $ 8.38 | $ 21.54 |

3F40T12 Electronic Ballast Price (non-tandem wired)

| 1F40T12 + 2F40T12 EMAG (ballast not in fixture, non tandem-wired) | 3F40T12 EL (ballast not in fixture) | Incre-mental Price | 3F40T12 EMAG Troffer (ballast + fixture) | 3F40T12 EL Troffer (ballast + fixture) | Incremental Price | Weighted Incremental Price | Weighted Total Price |
|---|---|---|---|---|---|---|---|
| $ 26.57 | $ 29.75 | $ 3.17 | $ 47.45 | $ 62.22 | $ 14.77 | $ 10.48 | $ 37.05 |

4F40T12 Electronic Ballast Price

| 2x2F40T12 EMAG (ballast not in fixtureballast not in fixture) | 2x2F40T12 EL (ballast not in fixture) | Incre-mental Price | 4F40T12 EMAG Troffer (ballast + fixture) | 4F40T12 EL Troffer (ballast + fixture) | Incremental Price | Weighted Incremental Price | Weighted Total Price |
|---|---|---|---|---|---|---|---|
| $ 26.32 | $ 47.24 | $ 20.92 | $ 47.45 | $ 62.22 | $ 14.77 | $ 17.05 | $ 43.37 |

4F32T8 Electronic Ballast Price

| 2x2F40T12 EMAG (ballast not in fixture) | 4F32T8 EL (ballast not in fixture) | Incre-mental Price | 4F40T12 EMAG Troffer (ballast + fixture) | 4F32T8 EL Troffer (ballast + fixture) | Incremental Price | Weighted Incremental Price | Weighted Total Price |
|---|---|---|---|---|---|---|---|
| $ 26.32 | $ 22.48 | $ (3.84) | $ 47.45 | $ 47.43 | $ (0.02) | $ (1.43) | $ 24.89 |

2F96T12 Electronic Ballast Price

| 2F96T12 EMAG (ballast not in fixture) | 2F96T12 Elec (ballast not in fixture) | Incre-mental Price | 2F96T12 EMAG Strip (ballast + fixture) | 2F96T12 Elec Strip (ballast + fixture) | Incremental Price | Weighted Incremental Price | Weighted Total Price |
|---|---|---|---|---|---|---|---|
| $ 21.63 | $ 32.08 | $ 10.45 | $ 32.63 | $ 54.05 | $ 21.42 | $ 17.36 | $ 38.99 |

***Less Common Ballasts***. For less common ballast types, we were not able to directly obtain distributor prices. For these ballasts we went to a nationwide supplier that stocks all of the less common ballasts and tends to receive orders for small quantities. In order to obtain pricing for these ballasts that would be comparable to the LBNL derived prices, we calculated the ratio between the average distributor price (from the LBNL prices) for the more common ballasts with the prices for them in the 1998/99 W. W. Grainger catalogue (number 389). The prices and the ratios for these ballasts are presented in the first four rows of Table 3.11 below. Prices for the remaining ballasts in the table were adjusted by dividing the Grainger catalogue "Each Price" by one of the ratios. All ballast prices in Table 3.12 are for ballasts sold separately, not as part of a fixture. Grainger's catalogue does not list fixtures equipped with these ballasts.

Column 1 Ballast Type
Column 2 Grainger Stock Number from the (W. W. Grainger catalogue #389)
Column 3 Grainger catalogue #389 " Each Price"
Column 4 For first four rows

Ratio of Grainger "Each Price," column 3, to Average Ballast Price, Table 3.9 prices divided by 1.13.

For all other rows

All T12 magnetic ballasts use the ratio from the 2F40T12 magnetic ballast (1.87).

All T12 electronic ballasts use the ratio from the 2F40T12 electronic ballast (1.53).

All T12 cathode cutout ballasts are assumed to be priced similarly to the 2F40T12 electronic ballast (1.53). The annual shipments for the two types are similar.

All T8 electronic ballasts use the average of the ratios for the 2F32T8 and the 4F32T8 electronic ballasts, 1.95 plus 2.09 divided by 2 yields 2.02.

Column 5 LBNL-Calculated Average Ballast Price, column 3 divided by column 4
Column 6 LBNL-Average + 13%, column 5 plus 13% of column 5 (contractor to enduser markup)

**Table 3.12 Ballast Prices Based on Grainger Catalog (1997$)**

| Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 |
|---|---|---|---|---|---|
| **Ballast Type** | **Grainger Stock Number** | **Grainger catalogue #389 "Each Price"** | **Ratio of Each Price to LBNL Average Price** | **LBNL Calculated Average** | **LBNL Average + 13%** |
| **2F40T12 EMAG** | **6X922** | **21.80** | **1.87** | **11.65** | **13.17** |
| **2F40T12 EL** | **3V602** | **32.00** | **1.53** | **20.90** | **23.62** |
| **2F32T8 EL** | **1C206** | **34.70** | **1.95** | **17.79** | **20.10** |
| **4F32T8 EL** | **1C194** | **41.55** | **2.09** | **19.89** | **22.47** |
| 1F40T12 EMAG | 3X960 | 22.20 | 1.87 | 11.87 | 13.41 |
| 1F40T12 CC | 6V991 | 27.45 | 1.53 | 17.93 | 20.26 |
| 1F40T12 EL | 1C221 | 35.60 | 1.53 | 23.25 | 26.27 |
| 1F32T8 EL | 1C217 | 34.70 | 2.02 | 17.18 | 19.41 |
| 2F40T12 CC | 3V543 | 30.10 | 1.53 | 19.66 | 22.21 |
| 3F40T12 EL* | 1C202 | 40.30 | 1.53 | 26.32 | 29.74 |
| 3F32T8 EL | 1C896 | 40.30 | 2.02 | 19.95 | 22.55 |
| 2F96T12/HO MAG | 5X789 | 52.90 | 1.87 | 28.28 | 31.96 |
| 2F96T12/HO CC | 5X789 | 48.15 | 1.53 | 31.45 | 35.54 |
| 2F96T12/HO EL | 3V967 | 59.65 | 1.53 | 38.96 | 44.02 |

* The price for 3F40T12 EL derived here is used in the calculation of the average price for a 3F40T12 EL ballast weighted by a ratio of 2/3 and 1/3 sold within fixture and without fixture.

Table 3.13 (below) shows the ballast prices for all ballast types analyzed. For comparison purposes only, we also show the prices from the July 1997 Draft Report.[11]

**Table 3.13 Prices (in 1997$) for all Ballast Types Analyzed**

| Description | Lamp/Ballast Configuration | # of Ballasts | Feb. 99 - Ballast Price | Jul. 97 - Ballast Price |
|---|---|---|---|---|
| **4ft 1-LAMP FIXTURE** | | | | |
| EEM | 1F40T12/ES | 1 | 13.41* | 11.69 |
| CC | 1F40T12/ES | 1 | 20.25* | 17.60 |
| ERS T12 | 1F40T12/ES | 1 | 26.27* | 22.47 |
| ERS T8 | 1F32T8/RE70 | 1 | 20.10* | 18.69 |
| **4ft 2-LAMP FIXTURE** | | | | |
| EEM | 2F40T12/ES | 1 | 13.16† | 11.43 |
| CC | 2F40T12/ES | 1 | 22.21* | 16.32 |
| ERS T12 | 2F40T12/ES | 1 | 24.57‡ | 22.35 |
| ERS T8 | 2F32T8/RE70 | 1 | 21.54‡ | 20.12 |
| **4ft 3-LAMP FIXTURE (tandem wired)** | | | | |
| EEM | 2F40T12/ES | 1.5 | 19.76 | |
| CC | 2F40T12/ES | 1.5 | 33.32 | |
| ERS T12 | 2F40T12/ES | 1.5 | 36.86 | 25.03 |
| ERS T8 | 2F40T12/ES | 1.5 | 32.31 | 22.54 |
| **4ft 3-LAMP FIXTURE (not tandem wired)** | | | | |
| EEM | 1F40+2F40T12/ES | 2 | 26.58 | |
| CC | 1F40+2F40T12/ES | 2 | 42.46 | |
| ERS T12 | 3F40T12/ES | 1 | 37.05‡ | 25.03 |
| ERS T8 | 3F32T8/RE70 | 1 | 22.55* | 22.54 |
| **4ft 4-LAMP FIXTURE** | | | | |
| EEM | F40T12/ES | 2 | 26.34 | |
| CC | F40T12/ES | 2 | 44.42 | |
| ERS T12 | F40T12/ES | 2 | 43.37‡ | |
| ERS T8 | 4F32T8/RE70 | 1 | 24.89‡ | 24.56 |
| **8ft 2-LAMP FIXTURE** | | | | |
| EEM | 2F96T12/ES | 1 | 21.62† | 19.90 |
| EIS T12 | 2F96T12/ES | 1 | 38.99‡ | 30.49 |
| **8ft 2-LAMP FIXTURE/HO** | | | | |
| EEM | 2F96T12/ES | 1 | 31.96* | 32.85 |
| CC | 2F96T12/ES | 1 | 35.53* | 37.76 |
| ERS T12 | 2F96T12/ES | 1 | 44.01* | 46.42 |

* Prices from Grainger catalog after adjustment using price ratio of Grainger to phone data for other ballasts for which these data were available (See Table 3.12).

† Phone data collection - Individual Ballast Price only (See Table3.9).

‡ Phone data collection - Price weighted by proportion of ballasts sold individually and those sold in fixture (See Table 3.11).

***Ballast Price Variance***. The ballast prices we collected vary by distributors' locations and are likely be affected by other factors (which we did not investigate) such as annual sales of the distributor, size of order, or time of data collection. Therefore, we used a range of prices rather than an average incremental price in the LCC analysis. We assumed that a large enough set of ballast prices would yield a normal distribution, so we used a normal distribution for all of the incremental price input distributions for the LCC analysis.

We chose a 15% standard deviation relative to the mean for all of the incremental price distributions used as inputs to the LCC analysis. We have also calculated standard deviations for our large data sets for specific ballast types. The assumed 15 percent standard deviation compares well with the data from Table 3.11. For example, the standard deviations of the 17 values of 2F40 T12/ES magnetic and electronic ballasts were 14% and 20% of their mean values, respectively. For the 21 values of 2F32T8 electronic ballast prices, we calculated a standard deviation of 14% of the mean value. Additionally, we tested the sensitivity of the LCC results to this input assumption (standard deviation) and found the results to be insensitive to the size of the standard deviation. As a result of this distribution, we are using the range of ballast prices shown in Table 3.14.

**Table 3.14 Range of Prices (in 1997$) Used in LCC Analyses**

| Description | Lamp/Ballast Configuration | # of Ballasts | Mean Price | Min. Price | Max. Price |
|---|---|---|---|---|---|
| **4ft 1-LAMP FIXTURE** | | | | | |
| EEM | 1F40T12/ES | 1 | 13.41* | | |
| CC | 1F40T12/ES | 1 | 20.25* | 11.14 | 29.36 |
| ERS T12 | 1F40T12/ES | 1 | 26.27* | 14.45 | 38.09 |
| ERS T8 | 1F32T8/RE70 | 1 | 20.10* | 11.06 | 29.15 |
| **4ft 2-LAMP FIXTURE** | | | | | |
| EEM | 2F40T12/ES | 1 | 13.16† | | |
| CC | 2F40T12/ES | 1 | 22.21* | 12.22 | 32.20 |
| ERS T12 | 2F40T12/ES | 1 | 24.57‡ | 13.51 | 35.63 |
| ERS T8 | 2F32T8/RE70 | 1 | 21.54‡ | 11.85 | 31.23 |
| **4ft 3-LAMP FIXTURE (tandem wired)** | | | | | |
| EEM | 2F40T12/ES | 1.5 | 19.76 | | |
| CC | 2F40T12/ES | 1.5 | 33.32 | 18.32 | 48.31 |
| ERS T12 | 2F40T12/ES | 1.5 | 36.86 | 20.27 | 53.44 |
| ERS T8 | 2F40T12/ES | 1.5 | 32.31 | 17.77 | 46.85 |
| **4ft 3-LAMP FIXTURE (not tandem wired)** | | | | | |
| EEM | 1F40+2F40T12/ES | 2 | 26.58 | | |
| CC | 1F40+2F40T12/ES | 2 | 42.46 | 23.35 | 61.57 |
| ERS T12 | 3F40T12/ES | 1 | 37.05‡ | 20.38 | 53.72 |
| ERS T8 | 3F32T8/RE70 | 1 | 22.55* | 12.40 | 32.70 |
| **4ft 4-LAMP FIXTURE** | | | | | |
| EEM | F40T12/ES | 2 | 26.34 | | |
| CC | F40T12/ES | 2 | 44.42 | 24.43 | 64.41 |
| ERS T12 | F40T12/ES | 2 | 43.37‡ | 23.85 | 62.89 |
| ERS T8 | 4F32T8/RE70 | 1 | 24.89‡ | 13.69 | 36.09 |
| **8ft 2-LAMP FIXTURE** | | | | | |
| EEM | 2F96T12/ES | 1 | 21.62† | | |
| EIS T12 | 2F96T12/ES | 1 | 38.99‡ | 21.44 | 56.54 |
| **8ft 2-LAMP FIXTURE/HO** | | | | | |
| EEM | 2F96T12/ES | 1 | 31.96* | | |
| CC | 2F96T12/ES | 1 | 35.53* | 19.54 | 51.52 |
| ERS T12 | 2F96T12/ES | 1 | 44.01* | 24.21 | 63.81 |

* Prices from Grainger catalog after adjustment with price ratio of Grainger to phone data for other ballasts for which these data were available (See Table 3.12).
† Phone data collection - Individual Ballast Price only (See Table 3.9).
‡ Phone data collection - Price weighted by proportion of ballasts sold individually and those sold in fixture (See Table 3.11).

Because incremental prices were used in the LCC analysis, we show, in Table 3.15 below, the mean incremental ballast price and range of incremental prices used for each lamp/ballast combination. For example, for the 2F40 T12/ES lamp, the mean incremental price to convert from the baseline EEM ballast to an electronic T12 ballast is $11.41. Prices in the incremental ballast price distribution range from $6.27 to $16.53.

**Table 3.15 Range of Incremental Prices (in 1997$) Used in LCC Analyses**

| Description | Mean Inc. Price | Min. Inc. Price | Max. Inc. Price |
|---|---|---|---|
| **4ft 1-LAMP FIXTURE** | | | |
| EEM | NA | | |
| CC | 6.84 | 3.76 | 9.92 |
| ERS T12 | 12.86 | 7.07 | 18.65 |
| ERS T8 | 6.69 | 3.68 | 9.70 |
| **4ft 2-LAMP FIXTURE** | | | |
| EEM | NA | | |
| CC | 9.04 | 4.97 | 13.11 |
| ERS T12 | 11.41 | 6.27 | 16.53 |
| ERS T8 | 8.37 | 4.60 | 12.14 |
| **4ft 3-LAMP FIXTURE (tandem wired)** | | | |
| EEM | NA | | |
| CC | 13.56 | 7.46 | 19.66 |
| ERS T12 | 17.10 | 9.41 | 24.80 |
| ERS T8 | 12.55 | 6.90 | 18.20 |
| **4ft 3-LAMP FIXTURE (not tandem wired)** | | | |
| EEM | NA | | |
| CC | 15.88 | 8.73 | 23.03 |
| ERS T12 | 10.47 | 5.76 | 15.18 |
| ERS T8 | -4.03 | -5.84 | -2.22 |
| **4ft 4-LAMP FIXTURE** | | | |
| EEM | NA | | |
| CC | 18.08 | 9.44 | 26.21 |
| ERS T12 | 17.03 | 9.37 | 24.69 |
| ERS T8 | -1.45 | -2.10 | -0.80 |
| **8ft 2-LAMP FIXTURE** | | | |
| EEM | NA | | |
| EIS T12 | 17.37 | 9.55 | 25.19 |
| **8ft 2-LAMP FIXTURE/HO** | | | |
| EEM | NA | | |
| CC | 3.57 | 1.96 | 5.18 |
| ERS T12 | 12.05 | 6.63 | 17.47 |

NA means not applicable. All incremental prices are relative to the EEM baseline ballast price.

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